EUROPEAN ORGANIZATION FOR NUCLEAR RESEARCH

SPECTRUM OF CHARGED NON-STRANGE BOSONS IN THE MASS REGION FROM 3.0 TO 3.8 GEV

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1. INTRODUCTION

The mass spectrum of charged non-strange bosons X^- produced in the reaction $\pi^- p \rightarrow p X^-$ has been explored with the CERN Boson Spectrometer (CBS) in the mass region from 3.0 - 3.8 GeV. This is a continuation of a previous investigation in the mass region from 2.5 - 3.0 GeV [1] using the same method and instrument.

The spectrum shows five new resonances of more than 4 standard deviations significance at masses of M_X = 3.025, 3.075, 3.145, 3.475, and 3.535 GeV. These objects have narrow widths and seem to prefer low multiplicity decays.

2. METHOD AND INSTRUMENT

In the reaction $\pi^- p \rightarrow p X^-$ the mass of the X^- is given by $M_{X^-}^2 = (E_1 + m_p - E_3)^2 - p_3^2 - p_1^2 + 2p_1p_3 \cos\theta_{13}$, where subscripts 1 and 3 refer to the incident pion and the recoil proton, respectively.

The proton momentum is measured for protons emitted near 0° in the momentum range $0.4 < p_3 < 1.0$ GeV/c with a magnetic spectrometer consisting of wide-gap wire chambers[2] placed before and after a wide-gap magnet, and with a time-of-flight (TOF) system (Fig. 1).

Selected mass regions can then be investigated choosing the appropriate p_1. The average values of the different p_1's were calculated from beam magnet currents and also measured by the deflection of the incident beam in the magnetic spectrometer. The values agree to within 0.6%. For a given p_1, the relative momenta of the beam particles are measured by a set of 3 scintillation hodoscopes to within $\Delta p_1/p_1 = \pm 0.3\%$.

The chambers before the magnet also measure charged decay products of the X^- emitted within ±22.5° from the beam direction. This allows one to determine the interaction point and thus to correct the p_3 measurement for the energy lost by the proton in traversing the target. A rough counting of the number of charged particles which miss the chambers is made by counters surrounding the target (D counters in Fig. 1).

In the mass region $3.0 < M_X < 3.8$ GeV, the mass resolution is typically 20 MeV (FWHM), slightly better for low than for high masses ($\sim$ 20% variation over the mass range).

When several runs at different p_1 values are added the width of the resolution may increase by $\sim$ 10 MeV due to systematic errors in the p_1 determination. The uncertainty in the absolute p_1 determination corresponds to an uncertainty in scale of $\Delta M = \pm 20$ MeV.

The value of p_3 is derived from the combined magnetic and TOF momentum determination. It was checked that no significant deviations exist between the spectra derived from these two measurements.

3. RESULTS

Data were taken at incident momenta of p_1 = 10.5, 12, 13, 14, 15, and 15.5 GeV/c. These momenta were chosen in order to cover the mass region from 3.0 to 3.8 GeV, and in order to have any given mass region accepted at several incident momenta. Any structure must be seen in more than one run. The addition of runs at different p_1 values also serves as a check against any bias in the p_3 measurement. A shift in p_1 of 1 GeV/c will cause a corresponding shift of a fake structure, due to any such bias, of about 100 MeV in the missing-mass spectrum.

The geometrical acceptance of the system is smoothly rising with mass (for details see Ref. 1), since the c.m. angular acceptance increases with increasing missing-mass, i.e. as one approaches threshold. In order to see a structure, a flat background is desirable. In the figures shown below, we have therefore made a c.m. angular cut. In order not to lose too much statistics, we then have to consider rather narrow mass regions at a time. It has been checked that this procedure cannot produce false peaks.

We have divided the samples in a "high multiplicity" (more than three charged decay products seen) and a "low multiplicity" sample (three or fewer charged decay products seen).

Figures 2a and 2b show the mass region immediately above 3 GeV, obtained in the runs at p_1 = 10.5, 12, and 13 GeV/c; Fig. 2a in the low multiplicity selection; Fig. 2b in the high multiplicities. Whereas the high multiplicity sample is flat, the low multiplicity sample does show structure (the confidence level for a smooth curve in the interval $2.93 < M_X < 3.18$ GeV is $\sim$ 1%). The spectrum shows two peaks at masses of M_X = 3.025 and M_X = 3.075 GeV with widths $\Gamma \cong$ 25 MeV. Their significance over the hand-drawn background curve is 4.3 standard deviations and 4.1 standard deviations, respectively. Near the upper edge of the spectrum there appears to be a third peak. This, however, is better seen in Figs. 2c and 2d which give a detailed picture of the mass region $3.1 < M_X < 3.2$ GeV. The statistics are now higher, since the 14 and 15 GeV/c runs begin to contribute, and in the 12 and 13 GeV/c runs the solid angle acceptance is better. Figure 2c shows all multiplicities, and Fig. 2d the high multiplicities. Here there seems to be no dependence on multiplicity. The structure appears equally significant in both spectra. The strongest structure is the peak at 3.145 GeV with a width of < 10 MeV and a significance of 4.7 standard deviations over the background curve. The narrow spike at 3.18 GeV has a significance of 3.7 standard deviations; however, the width is less than our resolution.

The mass region $3.2 < M_X < 3.4$ GeV was covered in the runs at p_1 = 12, 13, 14, 15, and 15.5 GeV/c. In this mass region, a smooth curve gives a good fit to the spectrum. No structure exceeding 3 standard deviations is seen.

The mass region $3.4 < M_X < 3.8$ GeV is shown in Figs. 3a and 3b. Here data from the runs at p_1 = 14, 15, and 15.5 GeV/c are added. Figure 3a shows the low multiplicity events, Fig. 3b the high multiplicity events. As in the 3.0 to 3.1 GeV region, the high multiplicity sample is flat, whereas in the low multiplicity sample the confidence level for a smooth curve is $\sim$ 0.5%. The most prominent features are the two peaks at M_X = 3.475 and M_X = 3.535 GeV with widths of $\Gamma \cong$ 30 MeV. Their significance over the background line is 5.4 and 6.0 standard deviations, respectively. There is an indication at M_X = 3.605 GeV, of a third, less significant and less resolved peak.

A more detailed listing of the properties of the observed peaks are given in Table 1, where only peaks with > 4 standard deviations are taken into account.

4. CONCLUSIONS

In conclusion, we have shown that also at masses above 3 GeV, the boson spectrum is rich in structure. In the mass region $3.0 < M_X < 3.8$ GeV, five new resonances each with > 4 standard deviations significance have been found. At these high masses, the spacing between neighbouring peaks becomes so small that a kind of "sawtooth spectrum" is observed. If in any region the spacing should become closer or if the resolution were worse, the peaks would not be seen. (This might be an explanation for the apparent flat spectrum in the region $3.2 < M_X < 3.4$ GeV and the lack of structure in the high multiplicity samples.) To get a clear picture a detailed investigation of the different decay channels is needed.

Acknowledgements

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2) G. Chikovani, G. Laverrière and P. Schübelin, Nuclear Instrum. and Methods 47, 273 (1967).

Table 1

	Mass[a] (GeV)	Estimated[b] Width (FWHM) (MeV)	Statistical signif. st. dev.	Events in peak	Signal-to-background ratio	$\|t\|$ GeV/c	$d\sigma/dt$[c] $[\mu b/(GeV/c)^2]$	Estimated[c] σtot (μb)
$X^-(3.02)$	3.025	$\sim$ 25	4.3	280	1 : 12	0.21 - 0.39	150	20
$X^-(3.07)$	3.075	$\sim$ 25	4.1	200	1 : 12	0.23 - 0.44	80	10
$X^-(3.14)$	3.145	< 10	4.7	274	1 : 13	0.16 - 0.52	150	20
$X^-(3.47)$	3.475	$\sim$ 30	5.4	397	1 : 7	0.27 - 0.37	200	25
$X^-(3.53)$	3.535	$\sim$ 30	6.0	414	1 : 7	0.3 - 0.41	200	25

a) The error on the absolute mass scale is ±20 MeV. The relative error between the peaks is ±10 MeV.

b) These widths have been estimated for the background lines drawn in the figures. If the background were in reality lower, the widths would be correspondingly higher.

c) These cross-sections are less reliable than the other entries in the table. They contain the following uncertainties:
   i) background subtraction;
   ii) wide range of t and p_1;
   iii) the total cross-sections are extrapolated using $d\sigma/dt \sim e^{-8t}$.

Figure captions

Fig. 1 : Layout of CBS experiment (1969).

Fig. 2 : The mass spectrum of the X^- in the region $3.0 < M_{X^-} < 3.2$ GeV as observed in the reaction $\pi^- p \rightarrow p X^-$.

a) Sum of data from runs at $p_1 = 10.5$, 12, and 13 GeV/c. Selection of low multiplicity events (≤ 3 charged decay particles detected).

b) The same for high multiplicity events (more than three charged decay particles).

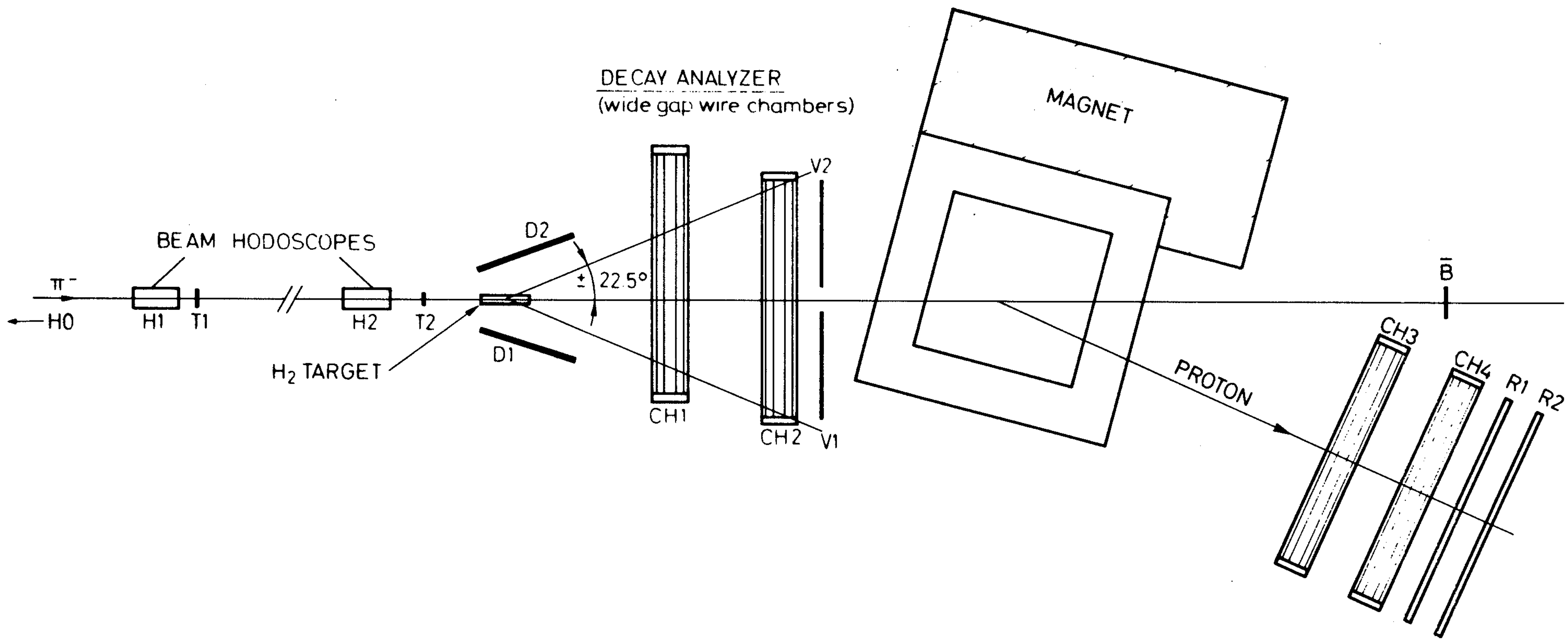
c) Sum of data from runs at $p_1 = 10.5$, 12, 13, 14, and 15 GeV/c. No decay selection.

d) The same for high multiplicity events.

Fig. 3 : The mass spectrum in the region $3.4 < M_{X^-} < 3.8$ GeV.

a) Sum of data from runs at $p_1 = 14$, 15, and 15.5 GeV/c. Low multiplicity selection.

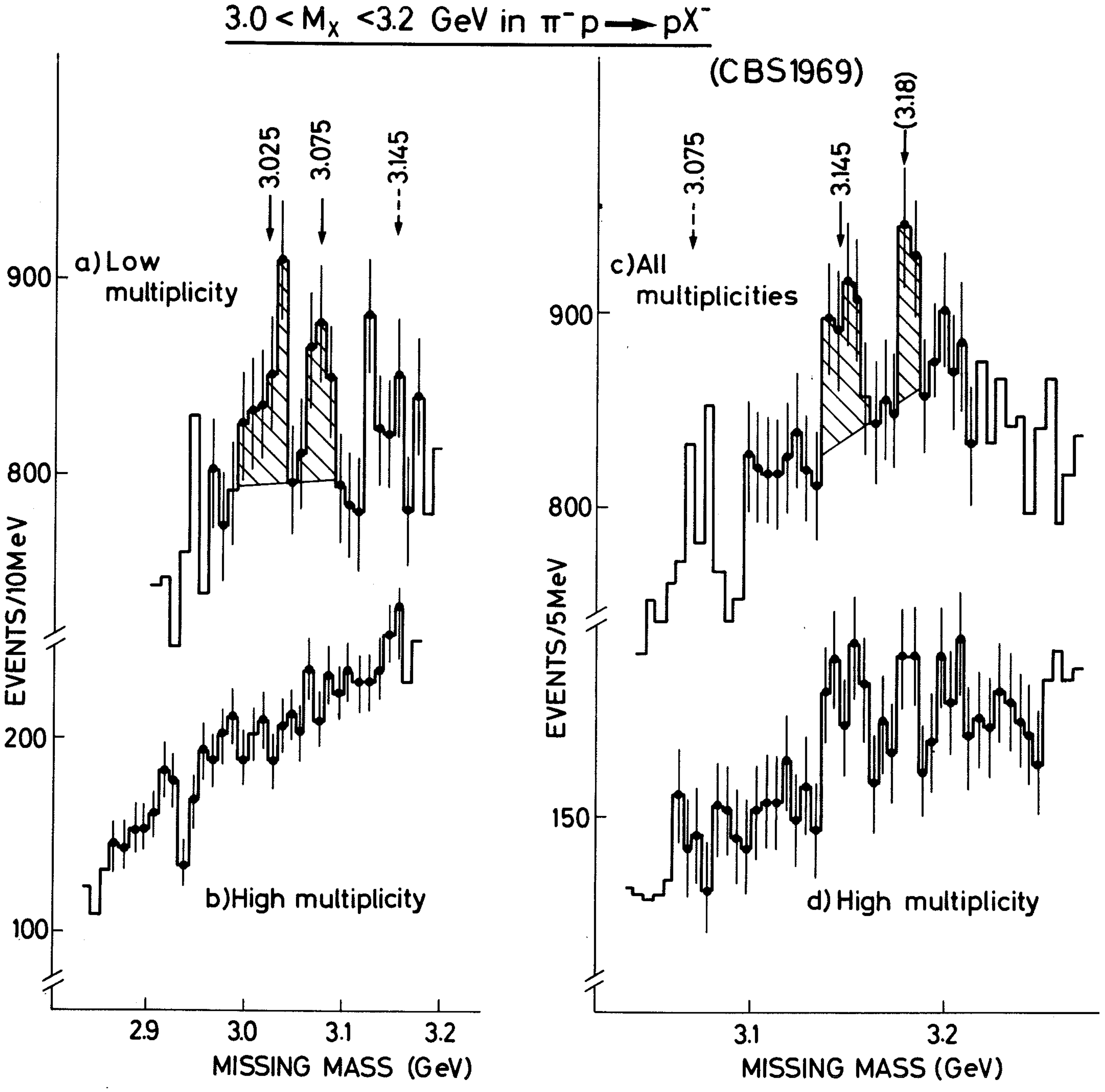
b) The same in high multiplicity selection.



Scale: ⊢———⊣ 1m

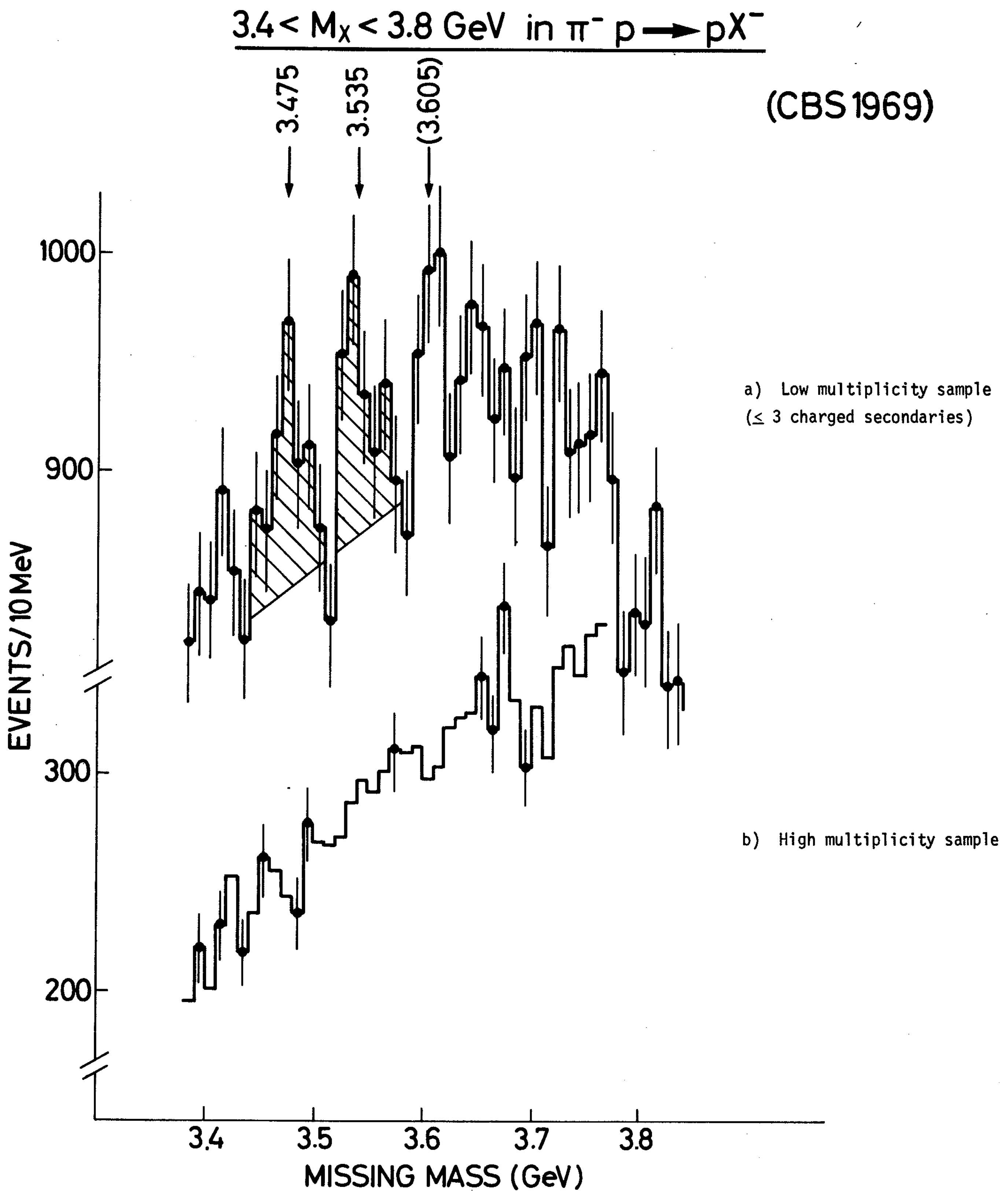
Trigger condition : $T_1\ T_2\ \bar{B}(V_1+V_2)R1\ R2$

FIG.1 CERN BOSON SPECTROMETER



3.0 < M_X <3.2 GeV in π⁻p → pX⁻
(CBS1969)
3.025
3.075
3.145
(3.18)
a) Low multiplicity
b) High multiplicity
c) All multiplicities
d) High multiplicity
EVENTS/10MeV
EVENTS/5MeV
900
800
200
100
150
2.9
3.0
3.1
3.2
MISSING MASS (GeV)

FIG. 2



3.4< M_X < 3.8 GeV in $\pi^- p \longrightarrow pX^-$
3.475
3.535
(3.605)
(CBS 1969)
1000
900
300
200
EVENTS/10 MeV
a) Low multiplicity sample
(≤ 3 charged secondaries)
b) High multiplicity sample
3.4
3.5
3.6
3.7
3.8
MISSING MASS (GeV)

FIG. 3